WIRELESS 3D AUDIO TRANSMISSION THROUGH BONE CONDUCTION

By

Amna Hamid
Muhammad Fahad
Muhammad Sharjeel Asif
Muhammad Shoaib

Submitted to the Faculty of Department of Electrical Engineering, Military College of Signals, National University of Sciences and Technology, Islamabad in partial fulfillment for the requirements of a B.E Degree in Telecom Engineering

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ABSTRACT

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According to a survey quoted in the HULT prize 2017 case study, more than 600 Million people are suffering from hearing impairment of various degrees globally [1]. Out of those 600 Million, 360 Million people are those who are born without the ability to speak or hear [2]. This makes up more than 5% of the total world population but the shortfall is so extreme that each year only 10 Million products are sold in this domain [1].

This is a wearable device that works as a replacement to customary headphones. It allows the hearing impaired people to regain their sense of sound who have lost their ability of hearing through some accident, incident or are just born this way. Apart from that, it also helps people in being more socially aware of their surroundings while they are listening to music on their phones through their headphones.

The idea of "Off-ear hearing" is employed in this project through the concept of bone conduction. It allows the user's ear canal to remain free and completely unblocked while he/she uses the headphones. The device bypasses the ear canal and delivers sound directly to the brain. In addition, the concept of "3D Sound Reception" is used through which sound is recorded all around the user using strategic positioning of microphones and transferred to the brain using the bone conduction mechanism in real time.

An application to accompany the device has also been developed based on android technology .This app provides an interface for the user to access device.

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Dr. Mir Yasir Umair

Project Supervisor

Military College Of Signals, NUST

Declaration

I certify that no portion of the work titled "Wireless 3D Audio Transmission through Bone Conduction" has been submitted in support of another award or qualification either at this institution or elsewhere. The material that has been used from other sources has been properly acknowledged/referred.

Signature of Team Lead

DEDICATED TO

OUR LOVING

PARENTS

ACKNOWLEDGEMENTS

We are thankful to our Creator Allah Subhana-Watala to have guided us throughout this work at every step and for every new thought which You setup in our mind to improve it. Indeed we could have done nothing without Your priceless help and guidance. Whosoever helped us throughout the course of our final year project, whether our parents or any other individual was Your will, so indeed none be worthy of praise but You.

We would like to thank our supervisor Asst. Prof. Dr. Mir Yasir who believed in us and was continuously supporting us in every problem that occurred during our final year project. We especially thank him for his encouragement and his accurate comments which were of critical importance, during this work.

We would like to dedicate this work to our beloved parents who always believed in us, always were there and will always be whenever we need them. We owe you everything.

Finally, we would like to express our gratitude to all the individuals who have rendered valuable assistance to our research.

PREFACE

The basis for this research originally stemmed from our passion for developing better methods to make the masses more socially aware as well as helping out the deaf community in our humble capacity. As the world moves further into the digital age, generating vast amounts of products to make people socially connected, there will be a greater need to access latest technology in suitable way which is not harmful to any individual. How will we regain sense of hearing and make people socially aware? It is our aim to not only find out, but to develop tools to regain sense of hearing along with social awareness.

TABLE OF CONTENTS

List of Figures

Key Symbols or Abbreviations

LUMEN	Wireless 3D Audio Transmission through Bone Conduction
ENT	Ear, Nose and Throat
ASMR	Autonomous Sensory Meridian Response
MCT	Multiple cranial transducers
OAEs	Otoacoustic emissions
TC	Tissue Conduction
BC	Bone Conduction
VNC	Virtual Network Computing
RFB	Remote Frame Buffer protocol
SSH	Secure Shell SSH
GPIO	General Purpose Input/ Output
DAC	Digital-to-Analog Converter
PWM	Pulse-Width-Modulated
DTO	Device Tree Overlay
SD	Secure Digital
AV	Waveform Audio format
CD	Compact Disc Digital Audio
CD-DA	Compact Disc Digital Audio
UI	User Interface
AUTOCAD	Automated Computed-Aided Design
FICS	Finding Innovative and Creative Solutions
LCDDP	Livelihood Center for Disability and Development Program Pakistan
DEMO	Demonstration (of something, such as a product or service)
CMH	Combined Military Hospital
NIHL	Noise-induced hearing loss

CHAPTER: 01

INTRODUCTION

1.1 - Introduction:

Nowadays, one of the most widely used objects is the "Headphone". They are available in two versions i.e. "In-ear" and "Over-ear". Each has its own merits and demerits. In addition, over 600 million people are suffering from hearing disabilities round the world [1]. So, the device which is being introduced here will be focusing on resolving these two major issues.

1.2 - Overview:

The dissertation presented will provide the basic idea behind the project titled "LUMEN (Wireless 3D Audio Transmission through Bone Conduction)", its detailed specifications, objectives, target audience and final deliverables.

The aforementioned product is a wearable device that will work as an alternative to normal headphones. The product employees the idea of "Off-ear hearing" through the concept of bone conduction. It allows the user's ear canal to remain free and unblocked while he/she uses the headphones. The device bypasses the ear canal and delivers sound directly to the brain through the skull bones. This, along with the concept of "3D Sound Reception" has resulted in a device that allows the hearing impaired people to regain their sense of sound in real time. Sound is recorded all around the user in real time using strategic positioning of microphones and is directly transferred to the brain using the bone conduction mechanism. The product/device has been interfaced with an android application via Bluetooth considering the ease of use for the user.

1.3- Motivation and Need:

The main motivation for taking up this project is to help those in the society which are not as fortunate as all of us. People who have lost their ability of hearing through some accident/incident or are just born without the ability to hear and speak. This device allows them to regain their sense of hearing once more as it bypasses the damaged eardrum to deliver sound directly to the brain.

Another motivation for making such a device is to make people more socially aware of their surroundings while they are listening to music on their phones through their headphones. Whenever a user plugs in his/her headphones he/she is completely cut off from the world and are not aware of what is happening around us. This is especially dangerous if anyone is on the road and is using headphones as most motorcycle riders do. This causes accidents on the roads as the rider doesn't know whether the road behind him/her is empty or crowded with vehicles. The correct usage of this device ensures that no such situation occurs resulting in precious lives being saved.

Another issue, though a minor one, that was aimed to be solved with this device was for people who exercise or jog regularly. People who like to run to maintain their physical fitness know this issue of their earphones continuously popping out of their heads due to the movement. This is nothing more than a nuisance but with the use of this device which will fit itself around the back of the head, there would be no popping out of the ears and it will make the experience better for the exercise enthusiast.

1.4 - Problem Statement:

Earphones are daily life commodities that are being used everywhere. For providing a sense of privacy, in a crowded and noisy place, their utility becomes more significant. However, earphones can make people socially unaware which can result in hazardous consequences in many ways. While one listens to music, he/she can get distracted and become unaware of the surroundings, this, in extreme cases, can lead to fatal accidents. Motorbike users are the most susceptible to this as they don't know when something may come up behind them and since they're using headphones to listen to music, they have no way of knowing it beforehand. Another issue that has been addressed is the fact that some people are not deaf by birth but lose their sense of hearing later on in life due to some accident or injury. In majority of these cases, the ear drum gets ruptured and it is not able to produce vibrations that need to be transferred to the brain to perceive sound. This causes them to go deaf in one ear or in other cases in both the ears. About the other category of deaf people, those that are born with the inability to hear or speak, they also require special equipment to regain their sense of sound.

Figure 1.1: Over Ear Headphones [8]

Figure 1.2: In Ear Earphones [9]

1.5 - Objective

This device provides added social awareness to the user all the while protecting his/her ear from excessive use of headphones which can lead to medical issues of various degrees. It will also be beneficial for people suffering from hearing impairment and allows them to once again experience sound around them. The device has been constructed in such a way that it is easily wearable and detachable instead of being an implantable device which has to be inserted surgically. The compact device is relatively cheap and user friendly when compared to the current devices available in the market.

1.6 - Approach:

On software, the device runs on a program that will allow two modes – The regular mode which will play music files for the user, picking up the playlist from the user's phone itself; and the recording mode which captures 3D sound from the surroundings and sends them to the brain in real time (thus enabling deaf people to hear again). For this, the microcontroller software "Raspbian" has been incorporated. In addition to that, audio manipulation software and Android Studio was also used for the development of the mobile application.

On hardware, the device is developed and manufactured in a shape similar to a headphone instead of an implant which allows for easy wear-ability and easy detachability whenever required. The difference being the fact that regular headphones rest on the ear or have to be "plugged in" the ear canal whereas this device rests on the zygomatic or the cheek bone and sound travels through the bones directly to the brain, thus, leaving the ear canal open to perceive sounds from the surroundings.

Figure 1.3: Over Ear Bone phones [10]

1.7- Project Scope and Intended Audience:

These earphones take into consideration both the qualitative and quantitative factors to provide the best quality sound at the least possible cost. This project is quite unique since, for the first time, it combines the concepts of 3D audio (which is different from normal recorded sounds we hear and make the source of sound more obvious) and the process of bone conduction. The Following figures were recorded around the globe and within Pakistan to have a better understanding of the target audience for this device:

- Hearing Impaired Global: 600 Million – 1 Billion [1]
- Hearing Disabled Global: 360 Million (More than 5%) [2]
- Pakistan Audience: 19.32 Million
- 5% outreach: Almost 1 Million

This project has many medical and consumer applications and it is suitable when the user wants to interact with the environment while listening to music during their daily routines. The concept of 3D audio also enables the user to hear binaural recording through which he/she can identify the exact position of the person speaking in that recording. The key beneficiaries of the product are as follows:

- The everyday consumer of the earphone, it will replace the usual headphones.
- The deaf community to regain their sense of sound.
- Military personnel for use during times of conflicts, combat training and rehearsals.

1.8 - Applications:

The applications of the device are enumerated as under:

- Regain the sense of sound and avoid the usage of hearing implants. This bone conduction mechanism is a great way for someone with conductive hearing loss or single sided deafness to have the benefit of audio streaming.
- Record unobstructed 3D sound from the surroundings and transfer them to the brain.
- Add the social awareness to the user and protect him from hazardous consequences of using headphones.
- Improve field communication especially in combat zones as it permits the military personnel to take up ambient sounds.
- Consider both qualitative and quantitative factors to provide best quality sound at the least possible cost.

CHAPTER: 02

Literature Review

2.1 - Introduction:

Some major topics that were researched before starting the project and their main conclusions are added and explained here. This research based study led to the progress and the development of the problem and its solution.

The basic question that was required to be answered was that whether or not the use of "Off ear hearing" and "3D audio recording", (when coupled with each other}, provide a real-life like experience for the users or not? In case of regular users, would it allow them to listen to music the same way as they would with traditional headphones? For the hearing impaired, would they be able to regain their sense of sound to an extent that it greatly impacts their everyday life?

Currently available in the market are the two kinds of headphones that the masses commonly use. They can be classified in the following two categories:

- In ear earphones (The ones that are plugged into the ear canal like with mobile phones)
- Off ear headphones (The ones that are bigger and rest outside the actual ear canal like gaming headphones)

This device will provide added social awareness to the user all the while protecting his/her ear from excessive use of headphones. It will also be beneficial for people suffering from hearing impairment and will allow them to once again experience sound around them.

The already existing knowledge will be referred related to bone vibration as a valid technology in both civic and private lines, when surrounding sound data or surrounding sound contamination are viewed as vital factors. Noise level in free places occasionally makes unbearable to concentrate on exact sound data. The likelihood of another "medium of sound" may be mostly helpful in circumstances wherever:

- The surrounding noise level is high or sound contamination is to be sidestepped
- The surrounding sound data is vital
- The normal private sound lines (such as cell phones) are upsetting to the surrounding or if autonomy of movement is needed.

In these circumstances, diverse employments of a bone vibration transducer could be very beneficial and could resolve or avoid the stated problems. It was decided to build a model of a bone conduction device, to test the likelihoods of this technology in day-today applications. We have taken help from various research papers on the topic and have come to know about the workings of the ear as well as how to by-pass the ear canal to fulfill the requirement of our device.

2.2 - Visit to CMH Rawalpindi:

During the research phase, team LUMEN had a meeting with the ENT (Ear, Nose and Throat) department in CMH Rawalpindi regarding the possibilities for the project and also to gain first-hand experience from the experts of the field. The information via this visit has gained, is explained in a few short points below:

- Sound waves enter the outside ear and travel over a tight section called the ear canal, which prompts the eardrum.

- The eardrum vibrates from the received sound waves and guides these vibrations to three moment bones in the focal ear. These bones zone unit known as the hammer, incus, and stapes.

- The bones inside the focal ear couple the sound vibrations from the air to liquid vibrations inside the tube-molded structure of the tangible receptor that is shaped kind of a snail and packed with liquid.

- Once the vibrations cause the liquid inside the tube-molded structure to swell, a wave frames on the basilar layer. Hair cells—tangible cells sitting on upper of the basilar layer—ride the wave. Hair cells near the wide complete of the snail-molded tube-formed structure sense higher-pitched sounds, for example, a newborn child crying. Those closer to the center see bring down pitched sounds, for example, an extensive canine yelping.

- Bending causes pore-like channels, which are at the tips of the stereocilia, to open up. Once that happens, synthetics hurry into the phones, making an electrical flag.

- The sound-related nerve conveys this electrical flag to the cerebrum, which transforms it into a sound that we recognize and decide.

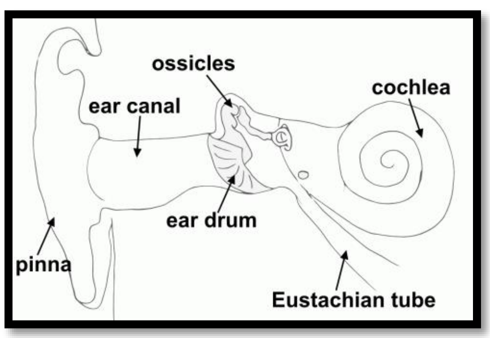


Figure 2.1: Basic Structure of Ear [11]

2.3 - 3D Audio Recording:

The second half of} the project relating to the 3D sound reception also required some research on team's part. The facts collected from various sources that 3D audio effects are a bunch of sound effects that manipulate the sound created by stereo speakers, surround-sound speakers, speaker-arrays, or headphones. This oftentimes involves the virtual placement of sound sources anywhere in three-dimensional area, along with behind, on top of or below the hearer. 3-D audio (processing) is that the spatial domain convolution of sound waves deployed Head-related transfer functions. it's the process of transmitting sound waves (using head-related transfer perform or HRTF filters and cross speak cancellation techniques) to imitate natural sounds waves, that originate from some extent in AN extremely 3D space. It permits deception of the brain using the ears and auditory nerves, pretending to position completely different sounds in numerous 3-D locations upon hearing the sounds, even though the sounds may {just|may|could} be created from just two speakers.

Traditionally, recordings are created deployed two methods: mono and stereo. Mono uses one microphone to select up sound, whereas stereo uses two, spaced apart from one another. stereo recording takes the stereo technique one step additional by inserting two microphones in ear-like cavities on either aspect of the top close to the two ears. The chimera creates three-dimensional audio. A surround electronic equipment takes up multiple speakers to make a 360-degree field around the hearer. However, by recreating specifically what your ear hears in any given situation, stereo audio accomplishes a way additional natural 3D sound without an expensive fleet of speakers.

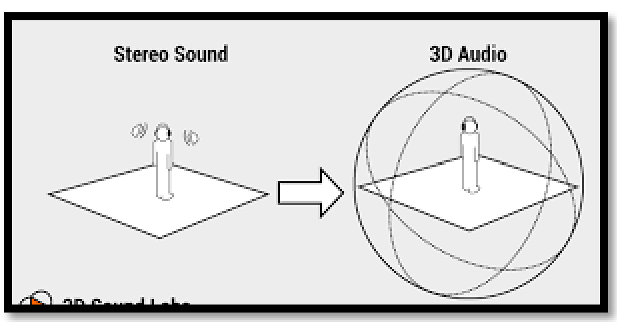


Figure 2.2: 3D and Stereo Comparison [12]

2.4 - Binaural Recording:

The method at the middle of stereophonic audio may be copied again to Clement Ader, a 19th-century French engineer. In 1881, Ader devised the Theatrophone, a telecommunication system of transmission to broadcast a Paris Opera show. In 1933, AT&T Bell Laboratories introduced stereophonic audio to the Chicago global's trustworthy. Through war II and consequently the many years that observed, development in stereophonic moon-confronted essential barriers: primitive strategies did not attain accurate, accurate recordings. But in 1973, Neumann, a known German electro-acoustic transducer enterprise, delivered the step forward KU-80, an epitome stereophonic recording tool. Stereophonic audio found an instantaneous pick recording groups: the technology worked properly for radio plays and experimental sound art. In the meantime, musicians like Lou Reed, Thom Yorke, and Imogen Heap have all experimented with stereophonic audio productions. Last, the ASMR (autonomous Sensory Meridian reaction) network has been the usage of stereophonic recordings to cause bodily responses that they consider can be soothing and calming.

2.5 - Bone Conduction:

Engrossing in the latest playlist or compelling audio book is a great escape when walking, running, cycling or driving, but it's a habit that greatly increases the risk of an accident; closing off to the outside world also closes off to trains, horns, and hollers. According to a 2012 study from the University Of Maryland school of medicine and therefore the University of Maryland medical center in city, 70 % of those accidents resulted in death.

The "Bone Conducted Microphone" senses the sound vibration then will increase and filtrates the signal. The sound vibration signal is generated from vocal muscle then transferred to body muscle, skin and bone, significantly the top bone. By applying this sound transfer principle, the "nose bone conducted microphone" was then invented. this type of microphones picks up the vibration signal from the nose bone.

Figure 2.3: Bone Conduction Headphones [13]

2.6 - Dry Skull Model:

The dry os model may be a beginning for understanding BC hearing mechanism in a very caput. This model shows mechanical purpose electrical resistance and tube-shaped structure acceleration. The simulation results may be accustomed predict vibration pattern of the bone encompassing the center and inner ear throughout BC stimulation. though there are variations within the vibration characteristics between a dry os and a person's head, the simulated result from the dry os may be useful once analyzing an intact caput with correct adjustment of the parameter values. Interest in Beethoven's deafness has long hypnotized his fans, several of whom are fascinated by the harmful circumstances of a deaf composer and therefore the ways that Beethoven managed to keep operating even once he fully lost his hearing by the time he was forty five. He composed music by scrunching a stick in his teeth, holding it against the keyboard of his piano, he might acknowledge faint sounds.

Audio signal processing or audio processing is that the deliberate adaptation of audio signals usually through an audio impact or effects unit. As audio signals is also electronically drawn in either digital or analog format, signal processing could happen in either domain. Analog processors activate directly on the electrical signal, whereas digital processors operate mathematically on the digital demonstration of that signal.

2.7 - Hearing Losses:

There are distinct kinds of hearing losses i.e. conductive listening to loss, Sensory listening to loss or Nerve deafness, combined listening to loss and BTE speech processor. The conductive/congenital hearing loss includes neural artesia (lack of an ear canal), "Strenosis" (constricted ear canal) and "Mictrotia" (missing or deformed outer ear). There are many genetic problems which lead to hearing disorder like Waardenburg syndrome (wide spacing between eyes, nose and eyebrows), connexian 26gene and Crouzone syndrome in which there is a deformity of inner ear or complete absence of ear canals that prevents growth of brain and skull plates become fused.

Multiple cranial transducers (MCT) are used to achieve auditory spatial sensory activity impressions via bone (BC) and tissue conduction (TC), bypassing the peripheral hearing equipment. MCT can be helpful in cases of peripheral hearing injury or wherever ear-occlusion is undesirable. By utilizing discrete signals, stereo and initial order ambisonics, externalization, range, direction in azimuth and elevation, movement and closeness are investigated.

2.8 - Otoacoustic Emissions:

There is a chance of estimating loudness characteristics on bone conductivity actuators by means that of acceleration. Otoacoustic emissions (OAEs) are accustomed estimate frequency characteristics of bone conductivity. The similar emissions were more established stimulus of bone conductivity at an equivalent frequency. there's chance of using otoacoustic emission as a technique for measuring frequency characteristics of bone conductivity actuators.

It relates to "Audio copy with management theory" which incorporates data concerning recovery of audio. The sounding vary is well known to be restricted to 0-20 kilohertz, and something on the far side is sharply cut (filtered out) by a low-pass filter. This is often based on the well-known Whittaker Shannon sampling theorem; all frequencies on the far side the Nyquist cutoff are considered noise. However, the Shannon formula is formal and therefore indirectly applicable to sound reconstruction/recovery. additionally, the high-end frequency (so-called Nyquist frequency) 22.05 kilohertz (half of the sampling frequency employed in digital audio) might not offer adequate margin in opposition to the hearable range. Digital filters used nowadays typically cut the frequency elements on the far side twenty kilohertz terribly sharply. However, this has the side impact of inducing:

- A giant sum of section alteration (phase error isn't considered within the typical Shannon paradigm).
- Ringing around twenty kilohertz because of the sharp-cut feature of the filter (Gibbs phenomenon). The unwanted alterations infringes below the Nyquist frequency too.

The first task of the project was to study about the philosophy of the task at hand. For this purpose there was a need to study various research papers and did extensive detail on the internet. The references that are being used throughout this paper are mentioned at the end in the bibliography.

CHAPTER: 03

Design and Development

3.1 - Introduction:

This chapter deals with the actual design and development of the device. The processes and strategies involved in bringing the device to life are discusses here. Every detail from the hardware to the software is under consideration in great depth in the following paragraphs of this chapter.

3.2 - Project Perspective

To develop the prototype of a device that delivers sound directly to the inner ear and brain thus bypassing the use of the ear drum. It also allows deaf people (with eardrum damage) to hear again since it all together bypasses the eardrum and creates vibrations in the skull bones instead. The 3D audio also provides an exact picture as to where exactly the sound is coming from.

3.3 - Design Requirements:

The project, as with any other machinery, should satisfy and comply with some basic and specialized user requirements, some of which are:

3.3.1 - Sound Quality:

Some headphones or earphones available in the market cannot yield the best sound for various reasons. The deterioration in sound quality will not allow a bit rate of higher than 128 Kbps to reach the user or in some cases it will stop at around 64 Kbps. This device delivers sounds at the highest bit rates of 320 Kbps or above and it will be achieved using sound manipulation software like MATLAB and Audiocity.

3.3.2 - Real Time Sound Transfer:

This device aims to transfer sound to the brain in real time without any lag. Though lag can never be removed altogether practically, but it has been minimized to the point that is barely noticeable by the user.

3.3.3 - Integration:

Since this is an amalgam of two separate technologies, it was of vital importance that they be compatible with each other. To achieve that, these two technologies were integrated with each other. These two devices after being integrated successfully have become extremely helpful to the hearing impaired community in regaining their sense of sound as well as being helpful to the general public in their everyday life.

3.3.4 - Compatibility:

The system has been designed in such a way that the hardware and software are completely compatible with each other. Hence, it has been designed such that the software used is compatible with the operating systems used on most machinery these days.

3.4 - Design Specifications:

The design consists of the following major components:

1. **Bone Conduction Transducers** – To transfer sound through bones
2. **Raspberry Pi Zero W** – As the main microcontroller of LUMEN
3. **Audio Microphones** – To Capture the 3D sound from the environment
4. **Battery Charging Modules** – To charge the Raspberry pi and keep it running
5. **Battery Charging Protection Modules** – To protect batteries from overcharging
6. **Rechargeable Batteries** – The power source of the project
7. **Battery Percentage Indicator Module** – To indicate the level of battery
8. **Audio Amplifiers** – To amplify the incoming sound before transferring it into the bones
9. **Printed Circuit Boards** – To create the electric circuit of our project

10. **Micro SD Cards** – To store data when phone is not connected
11. **Sound Card** – To render and capture high quality audio from a variety of sources.

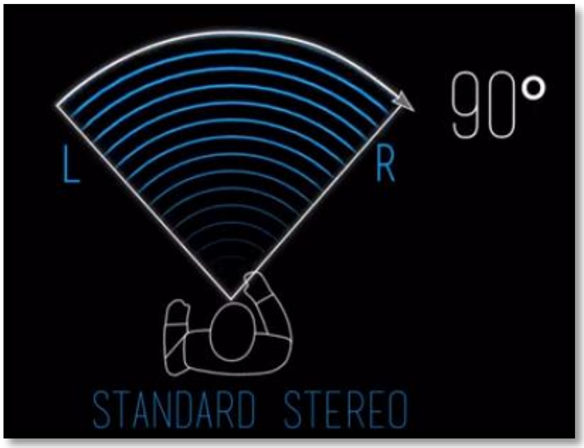
3.5 - Details of the Project and Development Route:

This section deals with the separate parts of the project. It explains in detail what the independent components are doing and how they are working together as a whole:

3.5.1 - 3D Audio:

The hearing capacity of human ear ranges from 20 Hz to 20 kHz. However, conventional audio recording devices provide only a vague picture of this. To deal with this issue, 3D audio is integrated into the device. Capturing 3D sound from the surroundings makes use of a technique called binaural recording. It makes use of multiple headphones placed on strategic locations to capture sound as a “3D” commodity. The headphones are attached to the headpiece of the device and it would rest on the cheek bone of the consumer. The sound, once played back (or listened to in real time), hence, gives an exact location as to where the sound is coming from. It makes use of a raspberry pi micro controller, high-end microphones to capture sound, amplifiers to amplify the sound, filters to improve the quality of sound and SD cards to store the incoming sound waves as .WAV or .MP3 files.

The following picture is clearly differentiating the 1D and 3D audio. In case of 1D, audio from side or rear is compromised and is only focused on front of the recording device. In case of 3D sound, the sound is easily represented as coming from above or below as well as front or behind the user with a full 360 degree capture.



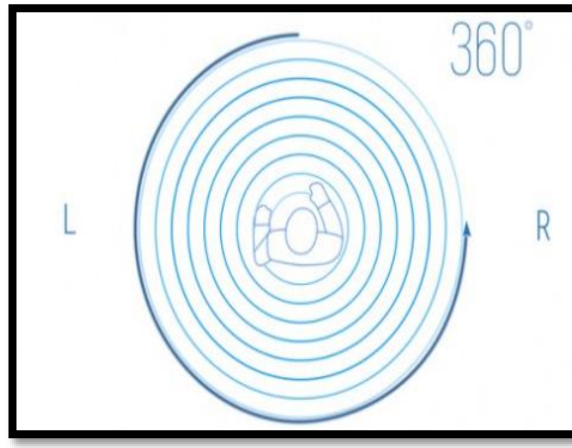


Figure 3.1 (a): Mono recordings [14]

Figure 3.1(b): 3D recordings [15]

3.5.2 - Bone Conduction:

Capturing the sound from the surroundings is one thing, transferring to the brain to be processed is another thing entirely. For that purpose, the concept of binaural recording is used. Speed and quality of sound varies in solids, liquids and gasses .It is best in solid in comparison with liquids and gases. So, Zygomatic Bone or "Cheek Bone" has been used as the input source. The earpiece that would rest on the cheek bone would produce vibrations pertaining to the incoming sound waves and these vibrations will be communicated through the skull bones straight to the brain where it would be interpreted as audible sound. This leaves the ear canal open and un-used which means that people with damaged outer ears will be able to regain their sense of sound. To achieve this, the device makes use of a Raspberry pi module, piezoelectric transducers, audio amplifiers and SD cards to store the data for processing.

The concept of audio conduction will be clearer if the methodology of bone conduction headphones is better understood. On the left side of the diagram, traditional headphones are shown in which the ear canal is used as a medium and this is from where the sound is communicated to the inner ear. On the other side, sound is communicated to the inner ear directly via the skull bones and there is no use of an ear canal in this case:

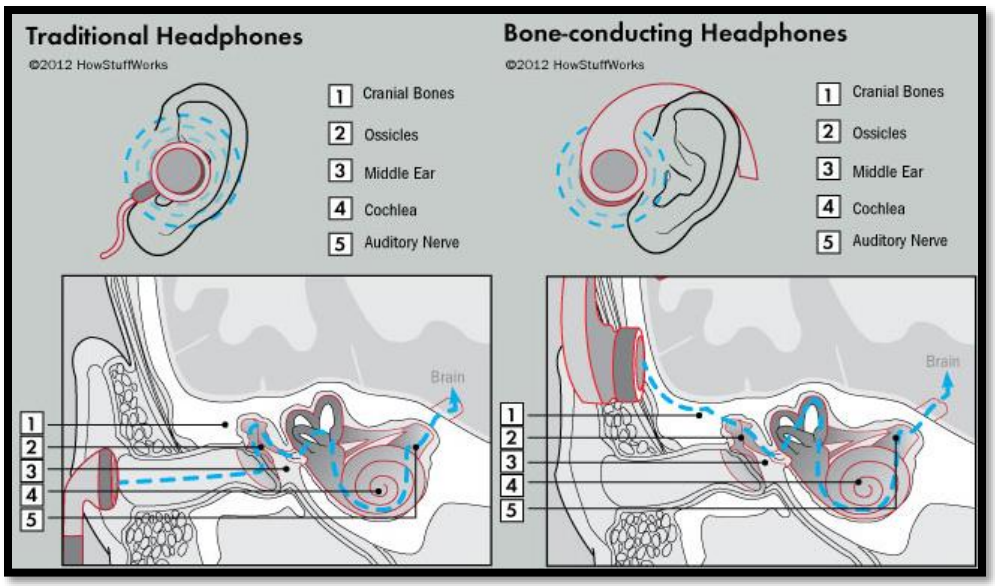


Figure 3.2: Comparison between Traditional headphones and Bone-conducting headphones [16]

3.5.3 - Mobile Application:

The device has been interfaced with a compatible mobile application that would be available to android devices made by any manufacturer. The device is completely controllable through the phone meaning tasks like increasing or decreasing the volume, switching between different modes of operation and turning the device on and off can be handled in an easy and comfortable manner. The software Android Studio was used to develop the application.

3.6 - Hardware Implementation:

The step by step implementation of hardware involved in the project is explained as follows:

3.6 .1- Purchasing and Testing Phase:

Some of the components were ordered online from various cities of Pakistan while a few were bought locally. Some of the most important pieces of equipment, including the Piezoelectric Transducers and the Amplifiers were not available in the country so order were placed for them from abroad . After receiving all components, hardware portion of the project was started. Audio Transducers were soldered with amplifiers and both transducers were tested at one time to get stereo sound. A "skeleton" was developed of our device on a breadboard with the available components. The circuit block diagram is as follows, this will make all the equipment and their uses clear from the outset:

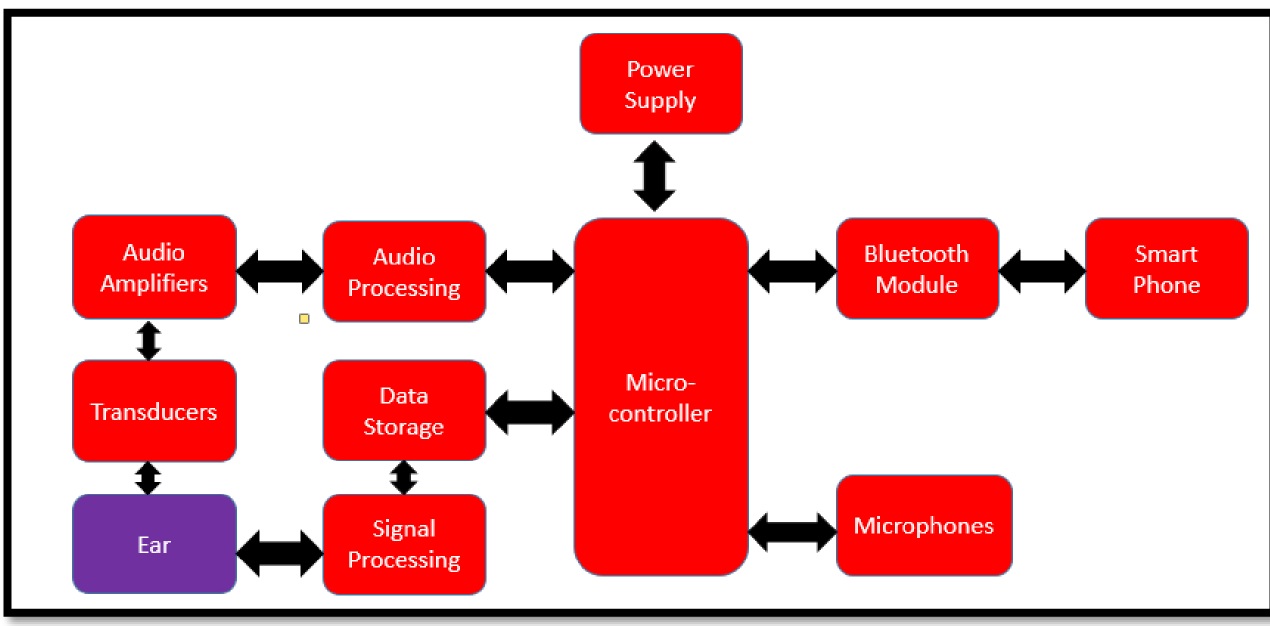


Figure 3.3: Circuit Block Diagram of LUMEN

3.6.2 - Initial Set-up of Pi:

In the initial phase Raspberry pi OS (Raspbian Stretch) was installed in SD card by inserting the card into PC, then the image file was mounted and burned into it. To establish connection over Wifi, the Pi zero was linked to PC. The following files were added into the default boot files:

- **wpa_supplicant.conf** for WiDi setting
- **ssh** to enable ssh

The ssh was created in "**boot.ssh"** as an empty text file. After creation of this file, it was named as "**ssh**" and saved to boot folder. Then for configuration of Wifi, "**wpa_supplicant.conf"** was created, its contents was copied to the system folder at boot time and deleted later as it is one time process.

"Advanced IP Scanner" was then used that search for available IP and is associated with the Pi. VNC server was downloaded and the IP was added to establish the connection of our IP with this server using following commands:

- **sudo apt-get update**
- **sudo apt-get install realvnc-vnc-server**
- **sudo apt-get install realvnc-vnc-viewer**

To update, the following command was used:

- **sudo apt-get update && sudo apt-get upgrade –y**

Login credentials were inserted and Pi OS screen showed an established connection. Pi was installed by using the command:

- **sudo apt-get install python-pip**

To following commands were also used:

- **Passwd,** to change the password
- **sudo raspi-config,** for initial configuration

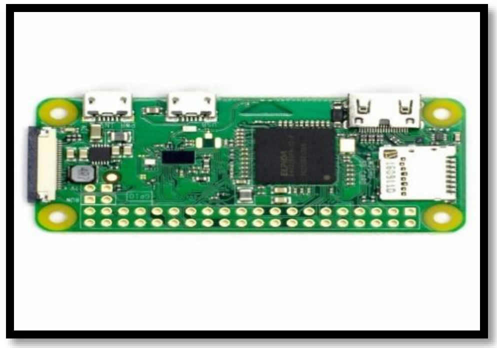


Figure 3.4: Raspberry Pi Zero W [17]

Headless Start:

A **headless system** is a computer system or device that has been designed to activate while not a monitor (the missing "head"), keyboard, and mouse. A headless system is often controlled over a network linking.

VNC Server:

In computing, **Virtual Network Computing (VNC)** is a graphical desktop distribution system that uses the Remote frame buffer protocol (RFB) to distantly manage another pc. It broadcasts the keyboard and mouse events from one pc to another, conveying the graphical screen updates back within the alternative direction, over a network.

SSH:

Secure Shell (SSH) is a cryptographic network protocol for in operation network services securely over an unsecured network. the most effective best-known example application is for remote login to pc systems by users. SSH provides a secure channel over an unsecured network in a client-server design, connecting an SSH consumer application with an SSH server.

3.6.3 – Acquisition of Good Quality Audio:

Since Pi zero does not contain a 3.5mm audio jack, so GPIO (General Purpose Input/ Output) pins are used for audio injection. But to get the audio out, 3.5mm audio jack has been utilized via DAC (digital-to-analog converter). Despite of using Broadcom chipset because of its drawbacks, PWM (pulse-width-modulated) pins are used at high speeds to filter the 50MHz output and adjusted the audio in the range of 20Hz to 20KHz .Due to non-availability of *PWM0* (pin #40) and *PWM1* (pin #45) on Pi zero, signals are re-routed to other pins. Device Tree Overlay (DTO) is accomplished to setup all pins and PWMs. Deprived of any external software or facilities, dtoverlay=pwm-2chan, pin=18,func=2, pin2=13, func2=4 is added to */boot/config.txt* .Then to eliminate noise, filters were used. After reconnection of Pi via SSH, reset the advanced setting and use the "*Aplay /home/pi/Downloads/Faded.wav*" command to play audio. To compromise size of audio file for better quality, WAV (waveform audio format) was applied instead of Mp3 codec as WAV files are uncompressed, lossless, broadcast CD quality audio files and is the right choice for loops to be processed with Flash for web animations. Rather, MP3 file is a compressed music file and for web pages, web videotapes, in fact for everything on the Internet. For CD (officially Compact Disc Digital Audio or CD-DA) audio, specifications are as follows,

- Sample Rate: 44,100 Hz
- Sample Size: 16 bit
- Bit Rate: 1411 kbps

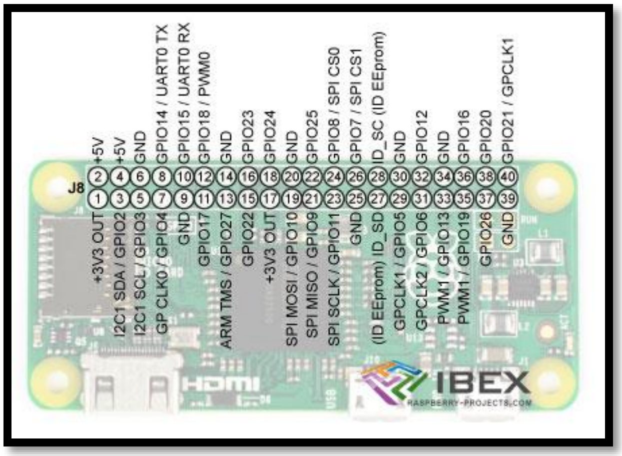


Figure 3.5: Pin Configuration [18]

3.6.4 - Recording and playing of Audio in Real time:

USB sound card is required to play audio as it enclose a microphone which records audio. Mono microphone is used with USB sound card and this card uses Digital to Analog convertor for recording function. **Lsusb** command was used after reboot the Pi, to check whether USB audio device is perceived or not. Device's card number is searched by **aplay –l command**. Then "asoundrc" file was created by using **sudo nano .asoundrc** and following text is added:

- pcm.!default { type hw card 1}
- ctl.default {type hw card 1}

Audio is recorded on audio card 1 and played on bone conduction transducers via audiocard zero which is our inbuilt card. These transducers are connected to GPIO pins. This process is done by using commands as follows:

- pcm.!default {type asym}
- playback.pcm "plughw:0"
- capture.pcm "plughw:1"
- ctl.!default{type hw card 1}
- alsamixer

The last command, sound is played and recorded in real time i.e

Play “|rec -d”

3.7 - Software Implementation:

The steps involved in developing the software segment of the device are explained in detail as follows:

3.7.1 - Languages and Softwares:

There was a need to learn the programming languages and the required softwares for this project. These included:

- Python
- MATLAB
- Raspbian
- Linux
- JAVA and XML
- Android Studio

Rasbian is used in RAPBERRY PI which is main controller of LUMEN. The basics of JAVA and XML for app development were required as entire device is interfaced with a mobile application that is available to android devices. The software which is used for app development is Android Studio. For signal processing techniques, frequency and time analysis, MATLAB and Simulink products are used.

3.7.2 - Android Application Development:

Android software development is the creation of new application for devices that runs on the Android operating system. The entire device is interfaced with a compatible mobile application that is available to android devices made by any manufacturer. The software which was used for app development is Android Studio. The devices were controllable through our phone meaning tasks like turning the Bluetooth on and off, making the device discoverable to other Bluetooth devices, showing the list of previously paired devices and will be handled in an easy and comfortable manner. For application development, JAVA and XML languages have been used.

3.7.2.1– Activity Main.XML:

In android, xml files are used for diverse functions. A layout describes the visual structure for a user interface (UI), such as the UI for an activity or app widget. UI elements declare a layout in XML. Android provides a simple XML terminology that corresponds to the View classes and subclasses, like those for widgets and layouts.
XML is a natural way to articulate a GUI's contents. It is permitted to say which layouts and components want to use in a human- and computer-readable form, and to specify their features, such as size, position and color. The snapshots for main activity on XML files are illustrated in Appendix A.

3.7.2.2– Android Manifest.XML:

Manifest xml is used to define all the components of application. It comprises the names of packages, Activities, services, receivers and the permissions that our application needs. The snapshots for android manifest on XML files are illustrated in Appendix B.

3.7.2.3– Strings.XML:

A string resource provides text strings for application with discretionary text styling and formatting. There are three types of resources that can provide our application with strings. String. XML resource provides a single string in Appendix C.

3.7.2.4– Main Activity.JAVA:

The **.java** source file is by default the **MainActivity.java** source file that creates all the activities having .java extensions and all the code behind the application. MainActivity.java is the actual file which gets switched to a dalvik executable and runs app. The snapshots for **MainActivity.java** is in Appendix D.

3.7.2.5 - App Layout:

The App layout demonstrates the background and its features i.e. Bluetooth turn ON, turn OFF, discover, List of previously paired devices and easily operated button for users.

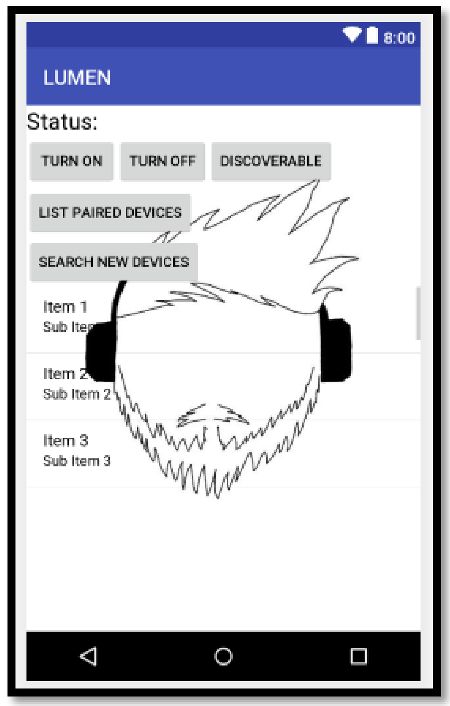


Figure 3.6: App Layout

3.8 – Casing:

The final step regarding the overall casing of the device is discussed in the following paragraph:

3.8.1 - 3D Modelling:

Using the prototype, dimensions were taken for its 3D modelling. **Automated Computed-Aided Design (AUTOCAD)** software was used to create 3D printable models. The models created with AUTOCAD resulted in errors which are reduced and corrected, and then its designing is verified before it is printed. After complete modelling, LUMEN is shown as:

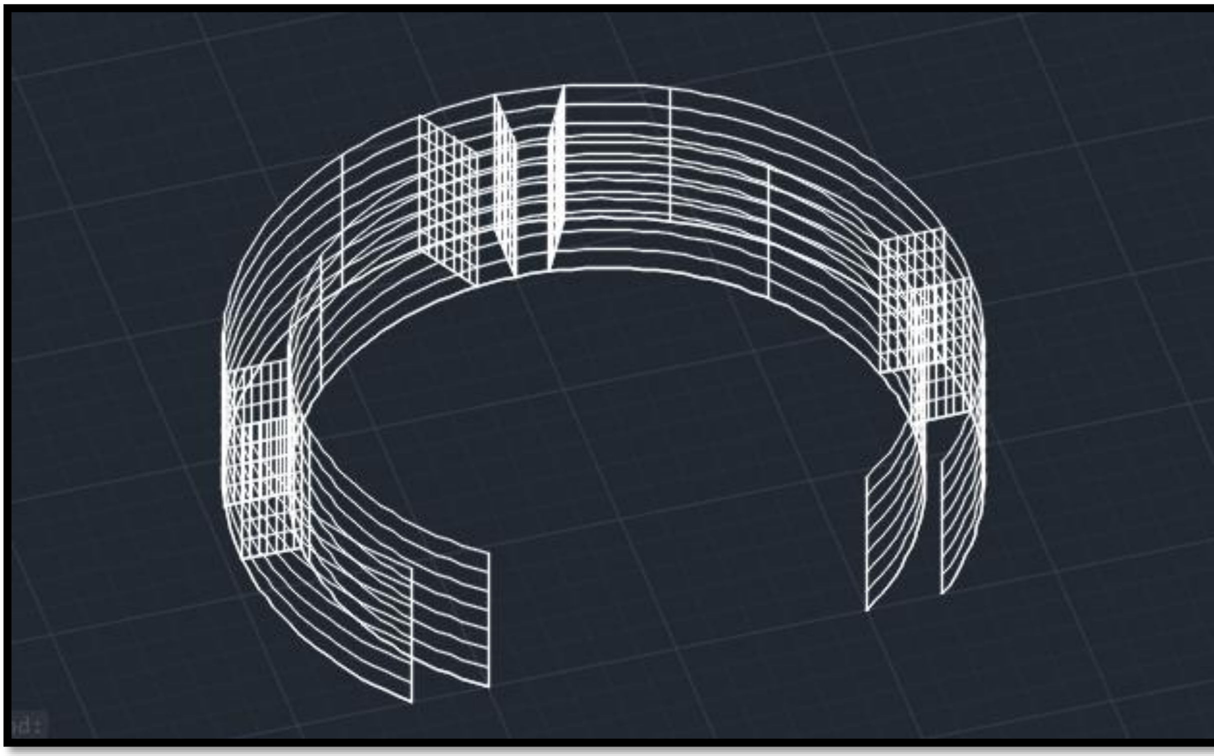


Figure 3.7: 3D Modelling on AUTOOCAD of prototype

3.8.2 - 3D Printing:

It is a process in which 3D dimensional object is created under computer control by joining and solidifying the objects. It is basically the speedy prototyping of the device usually by successively adding the material layer by layer. This technology was used for the casing of device to make it more user friendly by making easily wearable and detachable when required.

CHAPTER: 04

Project Analysis and Evaluation

4.1 - Introduction:

Qualitative and Quantitative methods are used for analysis of data and Interpretation. From the hypothesis behind the development of the device to the reviews and opinions of the general users, all of these phenomenons are discussed in this chapter using graphical representation as well. For the growth of device in market, business model was also been formulated using the appropriate modeling scheme.

4.2 – Qualitative Analysis of Data and Interpretation:

Qualitative method is used for this survey/research methodology.

4.2.1 - Research Details and Hypothesis:

The project, as with any other machinery, should satisfy and comply with some basic and specialized user requirements, some of which are:

- **Possibility:** The plausibility of the project being taken up. Whether the device can act as a viable and user friendly solution to the problem or not.
- **Implementation:** Is the technology being used in more or less the same manner anywhere else in the target market?
- **Quality:** Will it be possible to provide the same quality to the target audience as they are currently used to?
- **Acceptance:** Will this device be accepted by the target audience? Does it transcend any cultural or traditional stereotypes? Will the audience be willing to accept it as a radical solution to their problems?
- **Audience knowledge:** How much does the target audience know about the technology that LUMEN has introduced?

4.2.2 – Population:

To experience the utility of the device, team LUMEN conducted some surveys. The target audience of this survey takes account of the everyday consumer of the earphone, the deaf community to regain their sense of sound and military personnel.

4.2.3 - Sampling Technique:

The technique adopted for this survey and evaluation includes personal visits in public parks, schools, exhibitions, competitions, getting reviews of teachers, meeting principals and recorded feedback of students (of special educational institutes). As with any research project, various avenues or streams have to be used to gather data. We also wanted to target a wide range of audience both age wise, gender wise and education wise to attain as full a picture as we can possibly get with respect to the questions that we intend to put forward. The various data acquisition streams that we used include (but are not limited to):

Google forms: "Google Forms" was used to gather a wide range of audience through the power of the internet. More than 70% of the population of Pakistan has some access to internet and that is perhaps the biggest platform to gather un-biased data from a diverse range of subjects.

Audiologist's Opinion: Team visited CMH Rawalpindi ENT Department to gain firsthand knowledge from experienced audiologists.

Personal Visit: Team visited FG Sir Syed Special Education School Rawalpindi to test device on hearing impaired students. The types of cases that were tested there included both who lost their hearing capability either because of some accident or by birth.

Market Survey: Marketing research was recorded via DEMO in a Public Park. People experienced sound through their bones and shared their reviews with the host team.

Social Media: The recent boom in social media means that more and more users are joining the different platforms to connect to the world. Team LUMEN was also looking to tap into this stream to gather a huge amount of data through it.

Awareness Seminars: A good way to incorporate data in an efficient and swift manner is by through awareness seminars to a select audience.

Online Surveys and Questionnaires: The printed surveys were distributed among peers and they were asked to work on them and fill them. At the end, a bulk amount of data was collected.

Invitation for Exhibition: An NGO named "Livelihood Center for Disability and Development Program (LCDDP) Pakistan" invited team LUMEN to setup a stall in their exhibition. Device was tested and exhibited in front of chief guests. The chief guests shared their prestigious feedback.

Participation in Different Platforms: Team LUMEN participated in FICS (Finding Innovative and Creative Solutions) competition where the device was displayed for judges.

Trials: A few devices will be given out that will be designed to a select few audience and give them a time period to test it and then get back to team with the feedback.

The data was then analyzed mathematically and computationally. Different softwares like MS Excel were used to get an exact picture of what the data is showing. Further representing it in the form or charts will increase the "ease of read" for anyone in the team or any external auditor or any other interested person.

4.2.4 - Demographic study and Responses:

The target is audience is independent of gender discrimination. The reviews and feedbacks are recorded both from males and females. The reviews were also recorded from the deaf community as well as the casual users of headphones. Moreover, an online survey has also been maintaining the record of 205 individuals.

4.2.5 - Statistical technique:

The responses were transformed in form of percentages and evaluated statistical technique.

4.3 - Quantitative Analysis of Data and Interpretation:

The interpretation of the data gathered is discussed in this section:

4.3.1 - Interpretation via Pie-Chart

A public survey over the internet was performed by the team and the results are discussed below:

Public Survey:

A questionnaire was prepared to keep a record of the general survey from the public. This survey illustrates the rough estimate of the number of people who are effected from hearing disabilities, their casual use of headphones and their knowledge about bone conduction technology. 204 responses were recorded.

The 81% of respondents belong to age group of 18 to 24 year old. This survey is clear-cut representation of the youth who use headphones excessively.

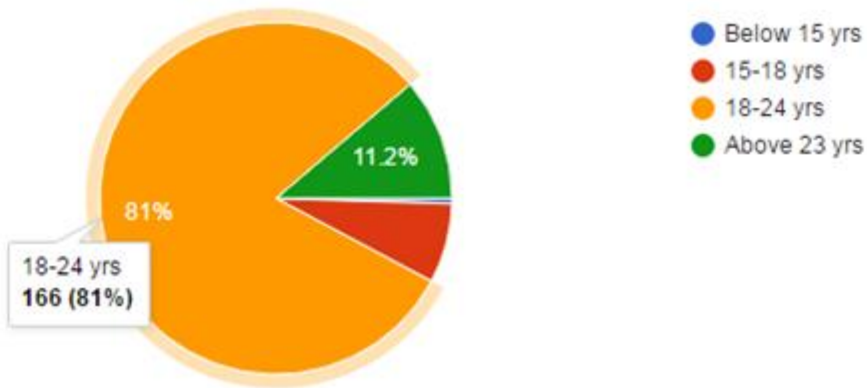


Figure 4.1: Average of Respondent's age [19]

Fig No. 2 illustrates that 40% of respondents have family income ranges from PKR 50,000 to 1lac.The purpose of including this question in questionnaire is to estimate the affordability criteria of latest but expensive headphones.

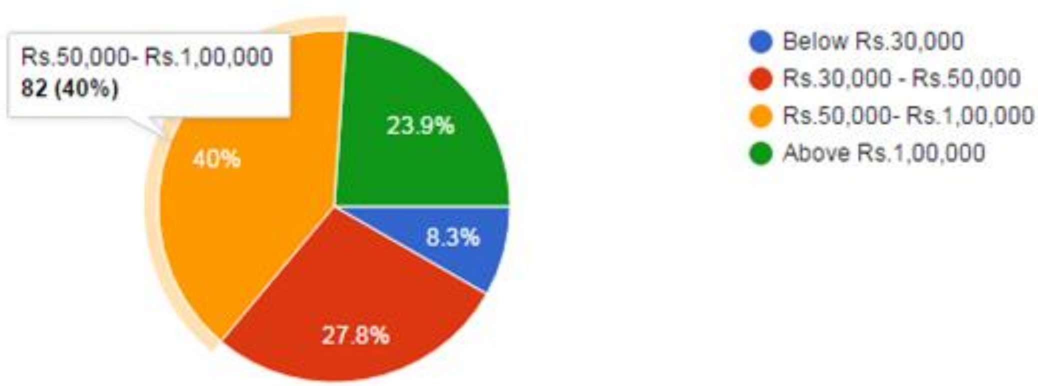


Figure 4.2: Information about Respondents family income[20]

Nowadays every second person is addicted of using earphones independent of the time, place and schedule.139 respondents recorded their feedback in favor of using earphones frequently. They collectively give 67.8%.

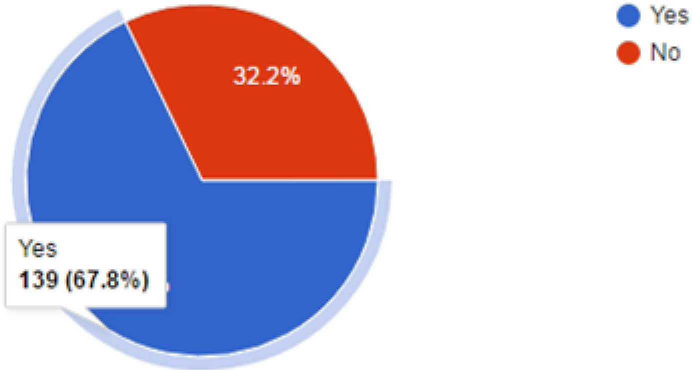


Figure 4.3: Usage of earphones[21]

People become bored so frequently from their daily life activities. To keep them entertained or relaxed in crowded area or while travelling, people use headphones. 154 respondents use it 3 to 4 hours a day on average.

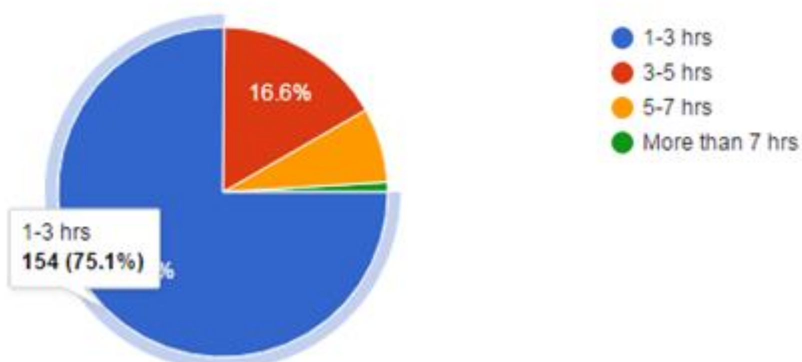


Figure 4.4: Average hours per day[22]

To estimate the affordability criteria of individuals of this device, this question was included in survey .Everyday consumer use headphones/earphones which lie in range that 49% respondents use headphones of less than 300Rs. Whereas 37.1% buy headphones of above 300Rs. Surprisingly, 20% respondents use headphones above 800Rs who can easily afford this device of latest technology.

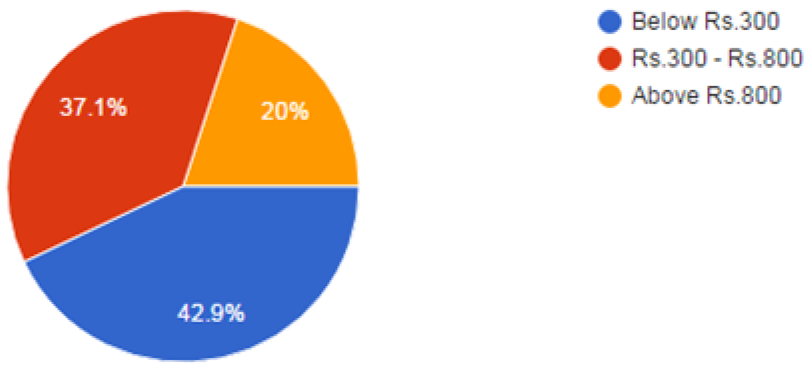


Figure 4.5: Cost of casually used earphones[23]

The purpose of this question is to test the device on hearing impaired people .46.8% respondents know people who are effected from hearing disability.

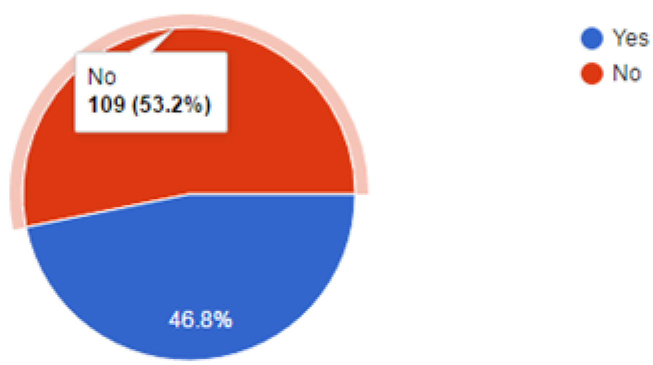


Figure 4.6: Information about hearing impaired individuals[24]

A lot of causes of hearing disabilities have observed in public survey. Some are deaf by birth, some people have lost their hearing capability either due to some accident or just because of senile or working in an industrial area for long period. The military personnel may have suffered from hearing disorder in war.

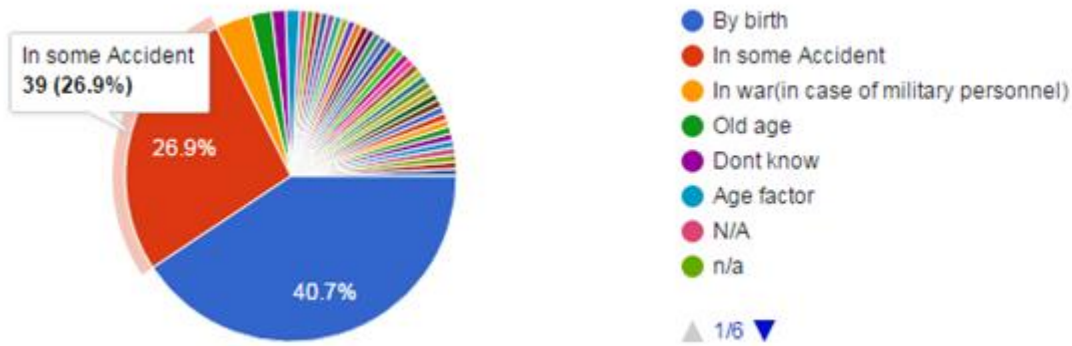


Figure 4.7: Information about possible causes of hearing impairment[25]

This device LUMEN can tackle hearing disorder in special parts of ear. So, if there is a knowledge of disorder part, then it is easy to say whether hearing impaired individual can regain his sense of sound or this device is not applicable for this area of impairments. According to survey, 16.9% respondents know hearing impaired people who have damaged inner ear.

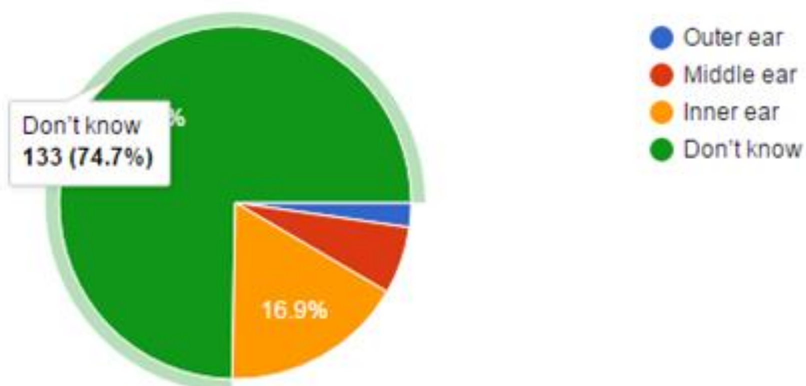


Figure 4.8: Information about part of effected ear [26]

In different cases, audiologists suggested different solutions. If there is a default in inner ear, sensory hairs or nervous system then mostly it is recommended either to use implantable device or to operate it depending upon the case. 23% of respondents got the advice of using a device which is easily wearable and detachable.

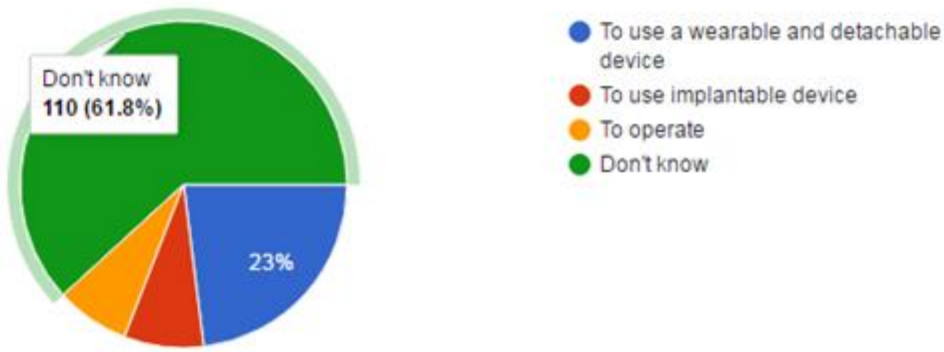


Figure 4.9: Suggested solutions of hearing impairment [27]

Around 600 million people are affected from hearing disabilities and people are unaware of sensitivity of this issue.

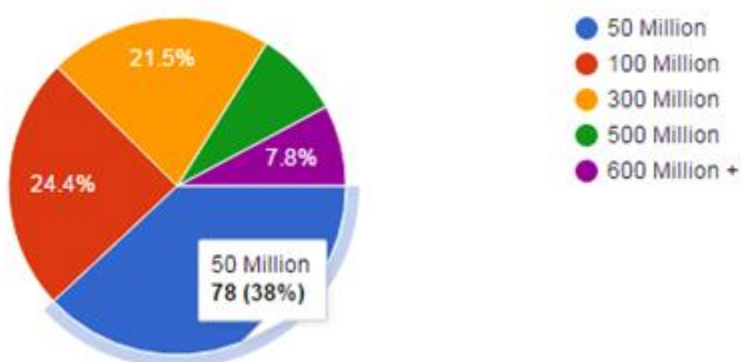


Figure 4.10: Information about average number of effected people [28]

The majority of respondents i.e. 72.2% are unaware of latest technology of audio conduction through zygomatic bones.

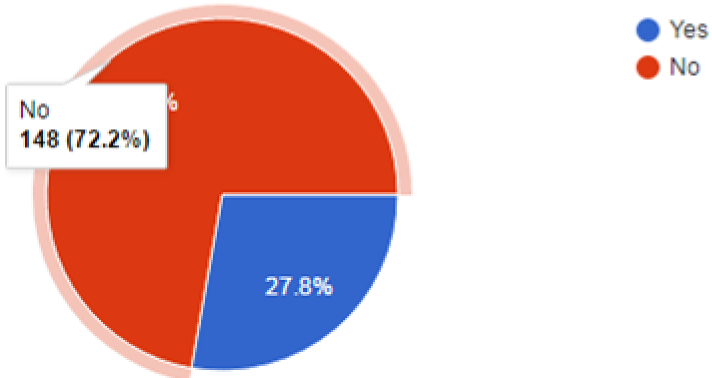


Figure 4.11: Information about Bone Conduction concept [29]

38% respondents use earphones while driving, motorcycling, swimming and rigorous exercising. They have to face issue of using casual headphones during these activities as they detach so easily while movement and they cutoff contact of user from social surroundings.

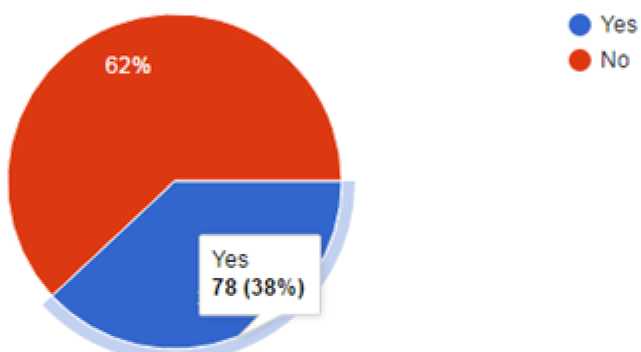


Figure 4.12: Data about usage of earphones during exercises [30]

159 respondents i.e. 77.6% of respondents are in favor of using such earphones which make them aware from social surroundings. While one listens to music, he/she can get distracted and become unaware of the surroundings which can be a cause for fatal accidents. Motorbike users are the most susceptible to this as they don't know when something may come up behind them and since they're using headphones they have no way of knowing it beforehand.

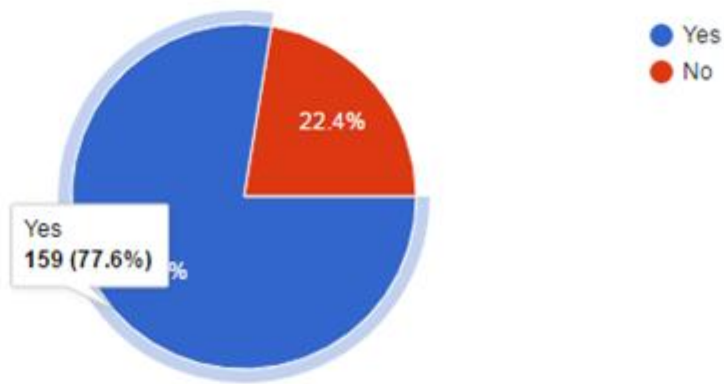


Figure 4.13: Respondents reviews about social awareness [31]

The traditional headphones record and play audio just in 2D in which, people are unaware from where the audio is coming from. But in case of 3D audio reception, device record audio in 3D which make the source of sound more obvious. 69.3% respondents are unaware of this unique technology.

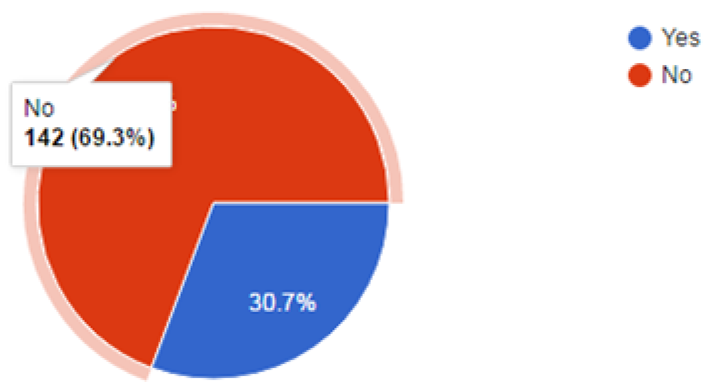


Figure 4.14: Respondents knowledge about 3D Audio[32]

With the increase in usage of headphones, this has almost become inevitable to use headphones which are responsible to perceive audio in real time. This will be a great benefit for deaf community as well as regular consumers. 72.2% respondents have recorded their feedback that they want to use a device in which 3D audio feature is added.

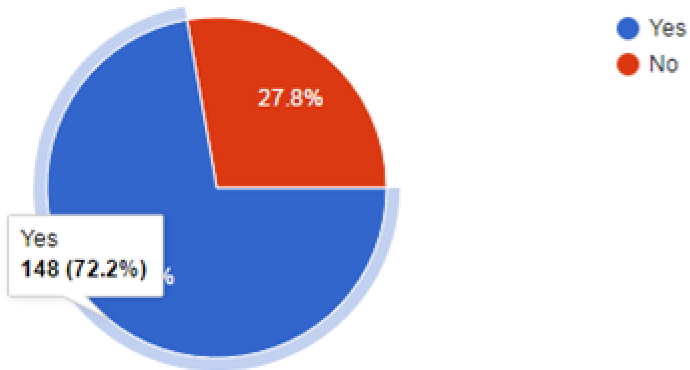


Figure 4.15: Respondents reviews about using latest technology [33]

4.3.2 - Interpretation via Graphs:

- **Google Survey:**

We analyzed following stats via Google survey which are essential for our device with respect to marketing point of view.

The sense of hearing gets effected with age. According to survey from authorized source, 30% females have to face hearing impairment at the age of 40 to 59. Whereas 32% men are suffered from this impairment at the age of 20 to 59.

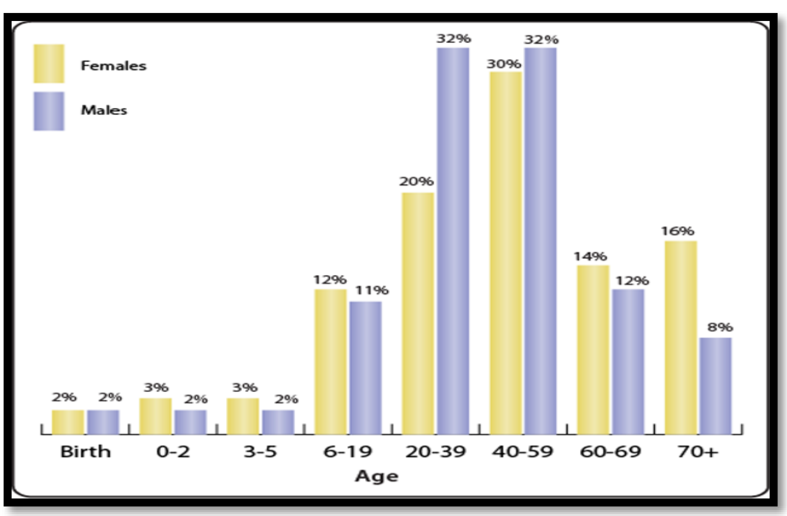


Figure 4.16: Age at which hearing loss begins [34]

Noise-induced hearing loss (NIHL) is hearing impairment consequential from contact to loud sound. Noise induced hearing loss occurs because of many reasons including Intensity of sound, Frequency of sound, Occupational noise, Non-occupational noise etc. The longer you are exposed to a loud noise, the more detrimental it may be. The following graph shows the usage of hearing aids by hearing impaired in adults:

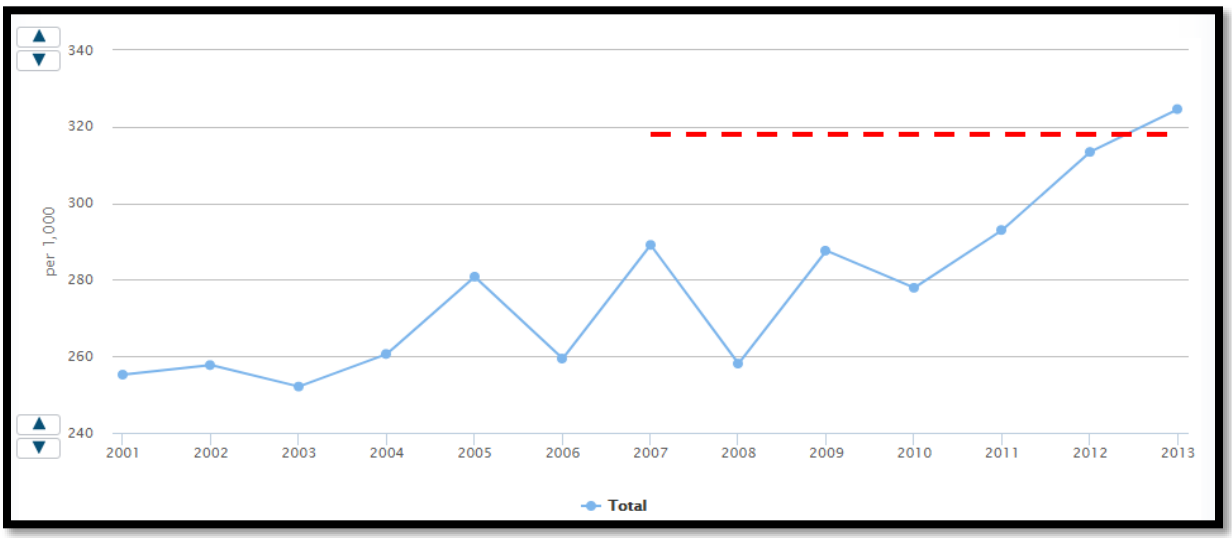


Figure 4.17: Use of hearing aids by adults with hearing loss (per 1,000 population) [35]

CHAPTER: 05

Discussions and Conclusion

5.1 - Introduction:

Findings are the outcomes which are gained after deep research and they tell us about the applicability of the device that how this device is beneficial and in which fields? After experimentation of the device, we came across through potential problems and key barriers that we faced. Also discusses in the chapter are the conclusions to our work and also some future work that can be taken up by any interested individual or industry.

5.2 - Findings:

So far, the audio output has been obtained by using the GPIO pins as pi zero does not have an audio jack. The sound has been captured using the 3D audio technology. They are further linked to piezoelectric transducers. These transducers are connected to GPIO pins of Raspberry pi zero. The mobile application has also been developed which can turn on and off the Bluetooth, can make the device discoverable to other Bluetooth devices, can show the list of previously paired devices and can search new devices. 3D printed case has also been used to fit around the head. The business model has prepared which is essential to monitor progress and recruiting tool for courting key employees or future investors.

5.3 - Potential Problems:

Though there were no profound problems that we had to face either technically or socially, some of the minor issues that we came across are as follows:

- Lack of audience interest
- Lack of funds
- Too narrow audience

5.4 - Key Barriers:

Some of the barriers and hurdles we faced while designing this device are enumerated as under:

- Size Constraint
- Conversion from Prototype to marketable product
- An accessory to wear on the head

While Bone conduction does have benefits, it isn't perfect. some of the disadvantages includes that it needs more power than standard audio, it suggests less frequency options, and crosstalk is sometimes gift. Despite this, the merits prevail over the demerits, therefore it's most likely expected to see bone conduction slowly however for sure taking on the globe of headphones and other personal audio.

5.5 - Future Work:

From the hardware perspective, there is a need of some improvement like working on multiple microphones at the same time, improved filtering and making two modes of the device. In terms of software, a switchable function can be made between modes and some activities can also be added in android application to make it more user friendly. To overcome all the key barriers is the main aim for future work. Also, to minimize the size of the product, a microcontroller can be designed to replace the Raspberry Pi that can easily take audio input/output and can play audio in real time using two microphones at a time as well.

5.6 - Conclusion:

A cheap wearable device has been assembled that works as a replacement to routine headphones. It permits the hearing impaired people to get back their sense of sound whether they have lost their capability of hearing through some accident or by birth. The device also makes people more socially aware of their surroundings while they are listening to music on their phones through their headphones.

The idea of "Off ear hearing" is employed through the concept of bone conduction. It allows the user's ear canal to remain open while he/she uses the headphones. The device bypasses the ear canal and conveys sound directly to the brain. In addition, the concept of "3D sound reception" is used which means that sound is recorded all around the user using strategic positioning of microphones and is transferred to the brain using the bone conduction mechanism. An application has been developed based on android technology. This app is interfaced with the device via Bluetooth for the user to turn on and off the Bluetooth and make the device discoverable to other Bluetooth devices. The user can check the list of previously paired devices and can search new devices. The 3D printed case was also designed to allow the device to easily fit around the head. A business model has with all its criteria was formulated which is essential to scrutinize progress and signing up tool for courting key employees or potential sponsors.

Sound interfaces in public areas generally neglect the privacy of "non-users" and contaminate the surroundings with noise. in a similar fashion, some private interfaces (such as mobile phones or headphones) may be disturbing in public places, uncomfortable or even dangerous in some circumstances wherever attention to the sound surroundings information is required (driving, walking, etc.). a straightforward solution has presented and an inexpensive prototype has been built in order to prove its viability. Bone conduction interfaces appear to be a good solution for the abovementioned circumstances, and its implementation in both public and private areas should be a subject of future study.

CHAPTER: 06

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CHAPTER: 07

Appendices

A. Main Activity.XML :

```
<?xml version="1.0" encoding="utf-8"?>
<RelativeLayout xmlns:android="http://schemas.android.com/apk/res/android"
    xmlns:app="http://schemas.android.com/apk/res-auto"
    xmlns:tools="http://schemas.android.com/tools"
    android:layout_width="match_parent"
    android:id="@+id/headerView"
    android:background="@drawable/bclogo"
    android:layout_height="match_parent"
    tools:context="com.example.muhammadshoaib.lumen.MainActivity">


    <TextView
        android:id="@+id/text"
        android:layout_width="wrap_content"
        android:layout_height="wrap_content"
        android:textAppearance="?android:attr/textAppearanceLarge"
        android:text="@string/Text" />

    <LinearLayout
        android:layout_width="match_parent"
        android:layout_height="wrap_content"
        android:orientation="horizontal"
        android:layout_marginTop="30dp" >

        <Button
            android:id="@+id/turnOn"
            android:layout_width="wrap_content"
            android:layout_height="wrap_content"
            android:text="@string/on" />

        <Button
            android:id="@+id/turnOff"
            android:layout_width="wrap_content"
            android:layout_height="wrap_content"
            android:text="@string/off" />

        <Button
            android:layout_width="wrap_content"
            android:layout_height="wrap_content"
            android:id= "@+id/discover"
            android:layout_alignParentTop="true"
            android:layout_alignParentLeft="true"
```

```
            android:text="DISCOVERABLE"
            />

    </LinearLayout>
    <LinearLayout
        android:layout_width="match_parent"
        android:layout_height="wrap_content"
        android:orientation="vertical"
        android:layout_marginTop="80dp" >

        <Button
            android:id="@+id/paired"
            android:layout_width="wrap_content"
            android:layout_height="wrap_content"
            android:text="@string/List" />

        <Button
            android:id="@+id/search"
            android:layout_width="wrap_content"
            android:layout_height="wrap_content"
            android:text="@string/Find" />

        <ListView
            android:id="@+id/listView1"
            android:layout_width="fill_parent"
            android:layout_height="200dp" >

        </ListView>

    </LinearLayout>

</RelativeLayout>
```

B. Android Manifest.XML:

```xml
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
   package="com.example.muhammadshoaib.lumen">
   android:versionCode="1"
   android:versionName="1.0" >
   <uses-sdk
      android:minSdkVersion="8"
      android:targetSdkVersion="19" />
   <uses-permission android:name="android.permission.BLUETOOTH"/>
   <uses-permission android:name="android.permission.BLUETOOTH_ADMIN"/>
   <application
      android:allowBackup="true"
      android:icon="@mipmap/ic_launcher"
      android:label="@string/app_name"
      android:theme="@style/AppTheme" >
      <activity
         android:name=".MainActivity"
         android:label="@string/app_name" >
         <intent-filter>
            <action android:name="android.intent.action.MAIN" />

            <category android:name="android.intent.category.LAUNCHER" />
         </intent-filter>
      </activity>
   </application>
</manifest>
```

C. Strings.xml :

```xml
<?xml version="1.0" encoding="utf-8"?>
<resources>

   <string name="app_name">LUMEN</string>
   <string name="action_settings">Settings</string>
   <string name="Text">Status: </string>
   <string name="on">Turn On</string>
   <string name="off">Turn Off</string>
   <string name="List">List Paired Devices</string>
   <string name="Find">Search New Devices</string>

</resources>
```

D. Main Activity.JAVA:

```
package com.example.muhammadshoaib.lumen;

import android.os.Bundle;
import android.app.Activity;
import android.bluetooth.BluetoothAdapter;
import android.bluetooth.BluetoothDevice;
import android.content.BroadcastReceiver;
import android.content.Context;
import java.util.Set;
import android.content.Intent;
import android.content.IntentFilter;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.ArrayAdapter;
import android.widget.Button;
import android.widget.ListView;
import android.widget.TextView;
import android.widget.Toast;

public class MainActivity extends Activity {

   private static final int REQUEST_ENABLE_BT = 1;
   private Button onBtn;
   private Button offBtn;
   private Button listBtn;
   private Button findBtn;
   private Button discoverabledevice;
   private TextView text;
   private BluetoothAdapter myBluetoothAdapter;
   private Set<BluetoothDevice> pairedDevices;
   private ListView myListView;
   private ArrayAdapter<String> BTArrayAdapter;
   private static final int REQUEST_DISCOVERABLE=0;

   @Override
   protected void onCreate(Bundle savedInstanceState) {
      super.onCreate(savedInstanceState);
      setContentView(R.layout.activity_main);

      // take an instance of BluetoothAdapter - Bluetooth radio
      myBluetoothAdapter = BluetoothAdapter.getDefaultAdapter();
      if(myBluetoothAdapter == null) {
         onBtn.setEnabled(false);
         offBtn.setEnabled(false);
         discoverabledevice.setEnabled(false);
```

```
            listBtn.setEnabled(false);
            findBtn.setEnabled(false);
            text.setText("Status: not supported");

            Toast.makeText(getApplicationContext(),"Your device does not support
Bluetooth",
                    Toast.LENGTH_LONG).show();
        } else {
            text = (TextView) findViewById(R.id.text);
            onBtn = (Button)findViewById(R.id.turnOn);
            onBtn.setOnClickListener(new OnClickListener() {

                @Override
                public void onClick(View v) {
                    // TODO Auto-generated method stub
                    on(v);
                }
            });

            offBtn = (Button)findViewById(R.id.turnOff);
            offBtn.setOnClickListener(new OnClickListener() {

                @Override
                public void onClick(View v) {
                    // TODO Auto-generated method stub
                    off(v);
                }
            });
            discoverabledevice = (Button)findViewById(R.id.discover);
            discoverabledevice.setOnClickListener(new View.OnClickListener() {
                @Override
                public void onClick(View view) {
                    if (myBluetoothAdapter.startDiscovery())
                    {
                        Toast.makeText(getApplicationContext(),"Making your device
Discoverable", Toast.LENGTH_LONG).show();
                        Intent enableBtIntent=new
Intent(BluetoothAdapter.ACTION_REQUEST_DISCOVERABLE);
                        startActivityForResult(enableBtIntent,REQUEST_DISCOVERABLE);
                    }
                }
            });

            listBtn = (Button)findViewById(R.id.paired);
            listBtn.setOnClickListener(new OnClickListener() {

                @Override
                public void onClick(View v) {
```

```
                // TODO Auto-generated method stub
                list(v);
            }
        });

        findBtn = (Button)findViewById(R.id.search);
        findBtn.setOnClickListener(new OnClickListener() {

            @Override
            public void onClick(View v) {
                // TODO Auto-generated method stub
                find(v);
            }
        });

        myListView = (ListView)findViewById(R.id.listView1);

        // create the arrayAdapter that contains the BTDevices, and set it to the
ListView
        BTArrayAdapter = new ArrayAdapter<String>(this,
android.R.layout.simple_list_item_1);
        myListView.setAdapter(BTArrayAdapter);
      }
   }

   public void on(View view){
      if (!myBluetoothAdapter.isEnabled()) {
         Intent turnOnIntent = new
Intent(BluetoothAdapter.ACTION_REQUEST_ENABLE);
         startActivityForResult(turnOnIntent, REQUEST_ENABLE_BT);

         Toast.makeText(getApplicationContext(),"Bluetooth turned on" ,
               Toast.LENGTH_LONG).show();
      }
      else{
         Toast.makeText(getApplicationContext(),"Bluetooth is already on",
               Toast.LENGTH_LONG).show();
      }
   }

   @Override
   protected void onActivityResult(int requestCode, int resultCode, Intent data) {
      // TODO Auto-generated method stub
      if(requestCode == REQUEST_ENABLE_BT){
         if(myBluetoothAdapter.isEnabled()) {
            text.setText("Status: Enabled");
         } else {
            text.setText("Status: Disabled");
```

```
            }
        }
    }

    public void list(View view){
        // get paired devices
        pairedDevices = myBluetoothAdapter.getBondedDevices();

        // put it's one to the adapter
        for(BluetoothDevice device : pairedDevices)
            BTArrayAdapter.add(device.getName()+ "\n" + device.getAddress());

        Toast.makeText(getApplicationContext(),"Show Paired Devices",
                Toast.LENGTH_SHORT).show();

    }

    final BroadcastReceiver bReceiver = new BroadcastReceiver() {
        public void onReceive(Context context, Intent intent) {
            String action = intent.getAction();
            // When discovery finds a device
            if (BluetoothDevice.ACTION_FOUND.equals(action)) {
                // Get the BluetoothDevice object from the Intent
                BluetoothDevice device =
intent.getParcelableExtra(BluetoothDevice.EXTRA_DEVICE);
                // add the name and the MAC address of the object to the
arrayAdapter
                BTArrayAdapter.add(device.getName() + "\n" + device.getAddress());
                BTArrayAdapter.notifyDataSetChanged();
            }
        }
    };

    public void find(View view) {
        if (myBluetoothAdapter.isDiscovering()) {
            // the button is pressed when it discovers, so cancel the discovery
            myBluetoothAdapter.cancelDiscovery();
        }
        else {
            BTArrayAdapter.clear();
            myBluetoothAdapter.startDiscovery();

            registerReceiver(bReceiver, new
IntentFilter(BluetoothDevice.ACTION_FOUND));
        }
    }

    public void off(View view){
```

```
        myBluetoothAdapter.disable();
        text.setText("Status: Disconnected");

        Toast.makeText(getApplicationContext(),"Bluetooth turned off",
              Toast.LENGTH_LONG).show();
    }

    @Override
    protected void onDestroy() {
        // TODO Auto-generated method stub
        super.onDestroy();
        unregisterReceiver(bReceiver);
    }

}
```